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Regeneration in Mixed Conifer Shelterwood Cuttings in the Cascade Range of Eastern Oregon

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METRIC EQUIVALENTS

1 acre	= 0.405 hectare
1 foot	= 0.3048 meter
1 inch	= 2.54 centimeters
1 mile	= 1.61 kilometers
1 square foot	= 0.0929 square meter
1 square foot/acre	= 0.2296 square meter/hectare
1 tree/acre	= 2.47 trees/hectare

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Regeneration in mixed conifer shelterwood cuttings in the Cascade Range of eastern Oregon

Reference Abstract

Seidel, K. W.
1979. Regeneration in mixed conifer shelterwood cuttings in the Cascade Range of eastern Oregon. USDA For. Serv. Res. Pap. PNW-264, 29 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of shelterwood cuttings in mixed conifer forests in the eastern Oregon Cascade Range showed that, on the average, shelterwood units were well stocked with a mixture of advance, natural subsequent, and planted reproduction of a number of species. Because of slow invasion by understory vegetation, frequent heavy seed crops, and adequate density of the overstory, natural regeneration was prolific on most units. Planting is recommended only as a supplemental reforestation method. Greater stocking was associated with increasing overstory density and more exposed mineral soil; such factors as aspect, slope, and elevation had a positive or negative relationship to stocking depending on the species and plant community.

KEYWORDS: Regeneration (stand), regeneration (natural), regeneration (artificial), mixed stands, Oregon (Cascade Range), shelterwood cutting method.

RESEARCH SUMMARY
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Regeneration of shelterwood cuttings in upper slope, mixed conifer forests in the eastern Oregon Cascade Range was surveyed for an overview of the status of reforestation and to identify key environmental factors influencing establishment of seedlings. Plots were randomly located in shelterwood units harvested during the 1970-73 period in the mountain hemlock/grouse huckleberry and mixed conifer/snowbrush-chinkapin plant communities in the Cascade Range.

On the average, shelterwood units were well stocked with a mixture of advance, natural subsequent, and planted reproduction of a number of species. An average of 63 percent of milacre quadrats were stocked in both plant communities, and density of seedlings of all origins averaged 4,483 per acre in the hemlock type

and 2,968 in the mixed conifer. Over 90 percent of the seedlings in both types were of natural postharvest origin. Although planted seedlings were only a small fraction of the total number of seedlings, the percentage of milacres stocked with planted trees was relatively high because of their good distribution over the plots. Planted seedlings were also dominant on more of the quadrats than their small numbers might suggest because of their greater height.

Greater stocking was generally associated with increasing density of the overstory and more exposed mineral soil. Other factors, such as aspect, slope, elevation, and understory vegetation, had a positive or negative effect on stocking, depending on the species and community. Equations for predicting stocking were derived for several species in both communities, but, because of the large amount of unexplained variation, they serve only as crude estimates of possible stocking.

Density of the residual overstory after the seed cut in a shelterwood method should be no greater than needed to obtain natural regeneration, so that established reproduction is not damaged or destroyed to an unacceptable degree when the overstory is removed. A range from 60 to 80 square feet of basal area per acre is recommended as the minimum level for establishing adequate natural regeneration in most shelterwood units in hemlock and mixed conifer communities. Logging and slash disposal operations in these shelterwood units broke up heavy, compact layers of litter and duff and exposed sufficient mineral soil for establishment of seedlings.

Only small amounts of understory vegetation were present in these shelterwood units. The slow invasion of understory vegetation, plus heavy seed crops every 3 or 4 years, and the uniform distribution of seed trees in shelterwood units resulted in an abundance of natural regeneration in most units. It appears that planting shelterwood units immediately after the seed cut is necessary only in the following cases: (1) in mixed conifer communities if residual basal area is reduced below 60 square feet per acre and (2) in pure mountain hemlock communities containing no other species in the overstory.

Blowdown of the residual overstory was greater in the mountain hemlock plots. The risk of blowdown can be reduced by marking leave trees which are fully crowned dominants or codominants (the most windfirm and also the best producers of seed) and by discriminating against mountain hemlock.

Removal of the residual overstory after the regeneration is established without unacceptable

loss or damage to the reproduction is essential if the shelterwood method is to be successful. The key to achieving this goal is good coordination between timber and fuels management staffs and skillful application of logging techniques designed to preserve established regeneration.

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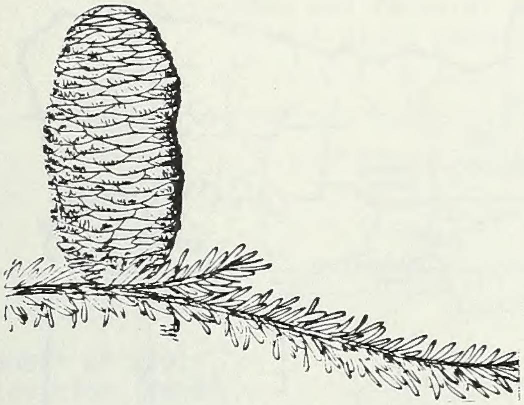

INTRODUCTION

During the late 1960's and 1970's, the shelterwood method has been used increasingly to harvest timber from upper slope mixed conifer forests of the east side Oregon Cascade Range. In some areas, this method has been tried as a means of modifying the harsh microclimatic conditions found on many high elevation clearcuts that cause difficulties in regeneration. And, as esthetic considerations became increasingly important, the shelterwood method was used in many areas open to public view to maintain the visual quality of the landscape.

Some of these shelterwood units are now old enough for regeneration to be established. Therefore, in 1978, I began a study to survey regeneration, the factors affecting its establishment, and the condition of the residual overstory. This paper reports the results of that field survey in 1978 on the Deschutes and Winema National Forests.

OBJECTIVES

The purpose of this study was to: (1) quantitatively evaluate the regeneration found on the shelterwood units, (2) evaluate condition of the residual overstories during the regeneration period, and (3) attempt to identify environmental factors associated with the presence or absence of regeneration.

Specific objectives were to:

1. Estimate success of regeneration in terms of stocking percentage and density (number per acre);
2. Estimate species composition of the regeneration;
3. Estimate stocking of regeneration of preharvest (advance) and postharvest (natural and planted) origin;
4. Estimate the relationship between regeneration and some measurable environmental variables, such as elevation, aspect, slope, and overstory density; and
5. Estimate survival and condition of the residual overstories.

STUDY AREAS

Study areas (plots) were located in the mixed conifer forest type of the eastern Cascade Range in

the Deschutes and Winema National Forests (fig. 1). A number of plant communities have been identified within this type by Volland (1976). Identification of these plant communities is based on the dominant overstory tree and the dominant understory shrub, forb, or grass. Plots were located in two of these communities: (1) a high elevation mountain hemlock/grouse huckleberry community and (2) a lower elevation mixed conifer/snowbrush-chinkapin community. The major tree species found in these communities are ponderosa pine (*Pinus ponderosa* Laws.), lodgepole pine (*Pinus contorta* Dougl.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.) white fir (*A. concolor* (Gord. & Glend.) Lindl.), Shasta red fir (*A. magnifica* var. shastensis Lemm.), western white pine (*Pinus monticola* Dougl.), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.). Understory vegetation in the mountain hemlock/grouse huckleberry community is generally sparse, consisting primarily of grouse huckleberry (*Vaccinium scoparium*), prince's pine (*Chimaphila umbellata*), and pine-mat manzanita (*Arctostaphylos nevadensis*). Major understory vegetation in the mixed-conifer/snowbrush-chinkapin community consists of snowbrush (*Ceanothus velutinus*), golden chinkapin (*Castanopsis chrysophylla*), pine-mat manzanita, and dogbane (*Apocynum pumilum*).

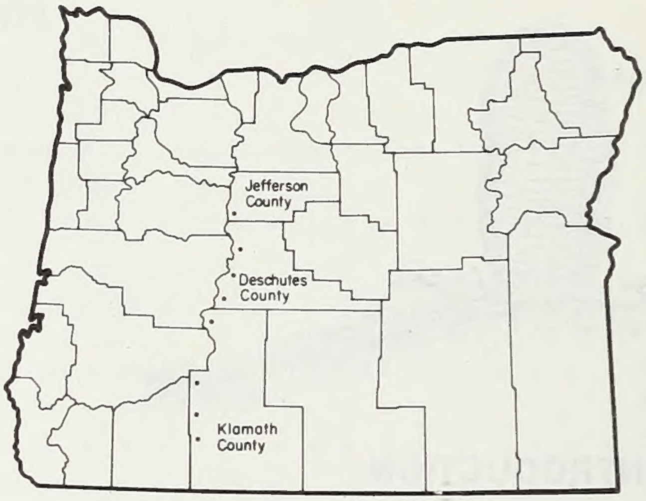

Figure 1.--Location of study areas in Oregon; eight to ten 10-acre plots were sampled in the vicinity of each dot.

Some characteristics of the shelterwoods sampled are given in table 1. In the mountain hemlock community, the number of trees per acre in the residual overstory ranged from 11 to 34, of which 51 percent were mountain hemlock, 35 percent red fir, 6 percent grand fir, 5 percent white pine, plus small numbers of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), lodgepole pine, and Douglas-fir. In the mixed conifer type, from 6 to 46 trees per acre remained in the overstory; the three dominant species were grand fir (52 percent), Douglas-fir (23 percent), and red fir (17 percent). Ponderosa pine made up about 5 percent of the overstory; a few lodgepole pine, white pine, and Engelmann spruce were also

Table 1--Mean and range of some characteristics of shelterwood units sampled in 2 plant communities in the Cascade Range of eastern Oregon

Characteristic	Mountain hemlock/ grouse huckleberry		Mixed conifer/ snowbrush-chinkapin	
	Mean	Range	Mean	Range
Number of plots	30	--	45	--
Elevation (feet)	5718	5,200-6,400	5,111	4,150-5,800
Slope (percent)	5.0	0-25	3.4	0-19
Age (years)	7.0	5-8	6.1	5-8
		Residual overstory		
Number of trees per acre	20.0	11-34	19.0	6-46
Average diameter (inches)	25.4	15.3-37.2	26.5	18.1-38.2
Basal area (ft^2)	65.7	20-186	68.0	16-183
Crown closure (percent)	30.1	15-53	32.1	8-75
		Seed bed (percent coverage)[1/]		
Mineral soil	16.3	0-37	22.0	4-43
Litter	31.1	6-66	30.7	12-57
Slash	15.6	7-24	12.2	6-30
Litter and slash	34.7	14-74	30.2	11-60
		Understory vegetation (percent coverage)		
Forbs	0.8	0-9	9.2	0-38
Shrubs	2.5	0-12	9.5	0-36
Grasses and sedges	3.6	0-20	9.0	0-34

[1/] Total of all seed bed categories do not add to 100 percent because areas of some milacre subplots are occupied by rocks and stumps.

present (fig. 2). Slash in 69 shelterwood units was piled by machine and burned after the seed cut, and in 6 units it was not treated.

Figure 2.--This shelterwood unit in the mixed conifer community contains an average of 16 trees and 50 square feet of basal area per acre.

Plots were within the pumice plateau region of south-central Oregon. Soils in this region are immature Regosols (Vitrandepts), developed from aerially deposited dacite and rhyolitic pumice ejected from Mount Mazama (Crater Lake) about 6,500 years ago. These well-drained, coarse-textured soils have thin A horizons, low in fertility, which grade into unweathered sand and gravel. A finer textured buried soil is found at a depth of 2 to 6 feet (Larsen 1976).

METHODS

Survey Design and Plot Selection

The mountain hemlock and mixed conifer plant communities were considered separate populations. A record of shelterwood units harvested in 1973 or earlier in the two communities was obtained from the USDA Forest Service Regional Office in Portland, Oregon. Only units at least 5 years old were considered suitable for sampling so that reproduction would have had time to become established. The sampling unit was a square plot 10 acres in size. Therefore, all shelterwood areas 10 acres or larger and at least 5 years old were considered candidates for sampling. The total number of 10-acre plots in each plant community was then determined; fractional portions of 10-acre areas were ignored. In the mixed conifer community, 216 plots were available for sampling and 145 in the mountain hemlock community.

I estimated that a total of about 75 plots could be sampled during the available time. Therefore, 45 plots were selectd at random from the total number in the mixed conifer community and 30 from the total in the mountain hemlock community. This resulted in a sampling intensity of about 20 percent.

Within each shelterwood unit, the sample plots were located the

same as sections are numbered in a township, beginning at the northeast part of the unit. Candidate sample plots were rejected if the shelterwood unit was seeded to trees or if it had been converted to nonforest uses. When a plot was rejected, it was replaced by another from a random list of alternate plots.

Data Collection

A grid of 25 sample points (subplots) was centrally located on each 10-acre plot. Circular subplots (quadrats) were systematically spaced at 66-foot intervals on five parallel lines 66 feet apart containing five subplots each. At each of the 25 sample point locations in the plot, three concentric subplots (1-milacre, 4-milacre, and 0.0785-acre) were examined for presence of regeneration, associated environmental variables, and condition of residual overstory. A sample point was rejected if conditions making it unsuitable for regeneration--streambeds, marsh or swamp, active roads, or gravel or cinder pits, solid rock, or erosion--occurred on more than one-half of a milacre subplot. Only 0.2 percent of the subplots were rejected for these reasons.

Information about the shelterwood unit and the timber stand in which it was located was obtained from Ranger District records and from field observations. Information obtained was the plant community in which the plot was located, average elevation of the plot, timber type, date of harvest, slash treatment method and year of treatment, species planted and year of planting, subsequent cultural treatments, and general notes on size, growth, and distribution of regeneration, or damage. The plant community was verified by observation of adjacent uncut stands.

On each 1-milacre subplot, the total number of seedlings of each species was counted and recorded by origin. Regeneration was classified as being of preharvest (advance) origin or of postharvest (subsequent) origin. Trees of subsequent origin were divided into 1- and 2-year-old seedlings from natural seed fall, seedlings 3 years and older from natural seed fall, and planted trees. On each 4-milacre subplot, the species and origin (advance, natural subsequent, or planted) of the seedling most likely to dominate the subplot because of its size and vigor were recorded. Four-milacre subplots were used for data on dominant seedlings to reduce the probability of unstocked subplots. On each 0.0785-acre subplot, the species and diameter at breast height (d.b.h.) of all standing overstory trees, including trees that died during the regeneration period, were recorded plus the species, number, and d.b.h. of windthrown trees.

Planted trees were identfied from information on species planted, date of planting, and spacing. In shelterwoods where survival was high, regular rows of planted trees were clearly visible. Identification of planted trees was less certain when survival was low, but counting whorls to check the age of a tree helped in determining planted trees.

The following environmental factors associated with each 1-milacre subplot were observed and recorded:[1/] Aspect, slope, condition of the seed bed (mineral soil, litter, slash), degree of burn, understory vegetation (forbs, shrubs, grasses), residual overstory density (basal area and percent crown closure), and presence or absence of animal damage.

Data Analysis

To illustrate the present status of reforestation, I summarized data in tables showing seedling numbers and stocking percentage of milacre subplots by species and origin for the plant communities. To determine the relationship between regeneration and environmental variables, I used stepwise multiple regression procedures to fit linear equations of the form $Y=b_0+b_1X_1+b_2X_2+...b_nX_n$ to the data. Dependent (Y) variables used were stocking percentages of milacre subplots and number of seedlings per acre of the various species and origins, and the independent (X) variables were the environmental factors given in the appendix[2/].

RESULTS AND DISCUSSION

Regeneration Stocking and Density

Regeneration on shelterwood units in both the mountain hemlock/grouse huckleberry and the mixed conifer/snowbrush-chinkapin communities was excellent for all species established before and after logging (fig. 3). An average of 63 percent of the milacre

Figure 3.--Natural regeneration in a mixed conifer shelterwood unit. Seedlings here are primarily grand fir and Shasta red fir and are 4 to 5 years old. Note absence of understory vegetation.

[1/] See appendix for details of procedures for measuring and coding the environmental factors.

[2/] Subplots were considered stocked if they contained at least one seedling.

subplots were stocked (all classes) in both plant communities, and seedling density (all classes) averaged 4,483 per acre in the hemlock type and 2,968 per acre in the mixed conifer type (table 2). Of the 4-milacre subplots, 88 percent were stocked in

Table 2--Average stocking percent and number of seedlings per acre of all species on shelterwood units in 2 plant communities in the Cascade Range of eastern Oregon, by class of reproduction[1/]

Class of reproduction	Mountain hemlock/ grouse huckleberry			Mixed conifer/ snowbrush-chinkapin		
	Number of plots	Mean ± S.E.[2/]	Range	Number of plots	Mean ± S.E.[2/]	Range
			Stocking percent			
Advance	30	9.5 ± 1.3	0-24	45	7.6 ± 1.1	0-28
Subsequent:						
1- and 2-year-old seedlings	30	28.3 ± 3.2	0-52	45	26.5 ± 3.4	0-88
3-year-old seedlings and older	30	45.9 ± 4.5	0-76	45	45.1 ± 3.6	4-92
Planted seedlings	15	20.0 ± 3.8	0-40	43	12.7 ± 1.7	0-36
All classes except 1- and 2-year-old seedlings	30	56.8 ± 3.8	8-92	45	57.1 ± 3.0	16-92
All classes	30	63.6 ± 3.8	16-92	45	63.2 ± 3.2	16-96
			Number per acre			
Advance	30	186 ± 35	0-800	45	162 ± 39	0-1,240
Subsequent:						
1- and 2-year-old seedlings	30	979 ± 182	0-3,000	45	894 ± 273	0-10,760
3-year-old seedlings and older	30	3,192 ± 583	0-12,400	45	1,781 ± 321	40-10,600
Planted seedlings	15	205 ± 36	0-880	43	134 ± 19	0-440
All classes except 1- and 2-year-old seedlings	30	3,504 ± 579	200-12,440	45	2,071 ± 327	200-11,200
All classes	30	4,483 ± 735	280-15,360	45	2,968 ± 569	120-21,960

1/ Based on 1-milacre subplots.

2/ S.E. = standard error.

the hemlock shelterwoods and 86 percent in the mixed conifer.

Postharvest natural regeneration made up the bulk of the seedlings in shelterwood units in both communities. In the mountain hemlock plots, 93 percent of the reproduction was of natural subsequent origin compared with 90 percent in the mixed conifer plots. Advance reproduction was a relatively minor component of the regeneration in both communities. This was expected because slash in nearly all shelterwood units was piled and burned, and much of the advance reproduction was destroyed. Planted seedlings were also only a small portion (5 to 10 percent) of the total number of seedlings on the planted plots. Because of their uniform distribution, however, the percentage of milacres stocked with planted seedlings was higher than the small number of seedlings might suggest (table 2).

Although 22 to 30 percent of the reproduction in these shelterwood plots consisted of 1- and 2-year-old seedlings, the effect of these seedlings was to increase the density of the regeneration rather than to greatly raise stocking levels. In the mountain hemlock shelterwoods, for example, stocking was increased on 73 percent of the plots; but on only 4 of the 30 plots was the gain more than 12 percent. In the mixed conifer shelterwoods, stocking was raised on 60 percent of the plots; but on only 7 of the 45 was the gain more than 12 percent.

Postharvest natural regeneration was found on all plots except in the mountain hemlock community, but there was a considerable difference in number of seedlings between five plots with an overstory of pure hemlock and plots with a mixture of hemlock, true fir, white pine, and lodgepole pine. In the pure hemlock plots, an average of only 104 seedlings per acre of natural subsequent origin were found, compared with 3,650 in the plots with a mixed overstory. The poor natural regeneration of mountain hemlock in contrast to the other species is probably due to the low residual overstory density (less than 50 ft^2 per acre).

Natural regeneration was established soon after the seed cut in the shelterwoods in both plant communities. Although the average age of these units is only 6 or 7 years, the largest single component of the reproduction is natural postharvest seedlings 3 years and older (table 2). For seedlings of this age to be present, sufficient seed fall must have occurred within 1 to 3 years after the seed cut.

During the 8-year period in which these shelterwood units were

cut, 2 heavy seed years occurred (1971 and 1974). Apparently most of the natural regeneration on the plots originated from these heavy seed crops. Obviously, a heavy seed fall occurring soon after the seed cut offers the best chance for successful establishment of seedlings because seed falls into loose mineral soil. Large amounts of seed also allow for losses to rodents and birds and for subsequent mortality. Although the bulk of the natural reproduction was from the 2 heavy seed years, seedlings of all possible ages were found in most plots. Thus, although heavy seed crops are ideal, it is possible to obtain satisfactory stocking from several light seed years as long as the seed bed remains receptive. Williamson (1973) also reported that adequate natural regeneration of Douglas-fir in the Cascades of western Oregon was obtained from establishment of seedlings during years of low seed fall. These observations suggest that it is desirable but not absolutely necessary to schedule seed cuts to coincide with heavy seed years.

In addition to overall average stocking of density of reproduction, a clearer picture of the status of regeneration on the shelterwood units can be obtained when plots are grouped into several stocking classes. Therefore, plots in both plant communities were grouped according to the number and percentage which attained specific levels of stocking or density (table 3). Depending on the definition of adequate stocking, the proportion of shelterwood units successfully regenerated can be determined. For example, if 40-percent stocking of milacre quadrats is considered satisfactory (at least 400 trees per acre), then 77 percent of mountain hemlock shelterwoods meet this standard compared with 84 percent of mixed conifer shelterwoods. Similarly, on a seedling density basis, 80 percent of the mountain hemlock shelterwoods and 76 percent of the mixed conifer plots had at least 700 seedlings per acre.

Because of the generally abundant natural regeneration, some plots were overstocked. In the mountain hemlock type, six shelterwood plots had more than 7,000 seedlings per acre and a density of 15,000 per acre was found on one plot; in the mixed conifer community, about 22,000 seedlings per acre were recorded on one plot. Overstocking of reproduction after the seed cut is not a serious problem, however, because some regeneration will be lost when the residual overstory is removed. If units are still overstocked after the final removal cut, stocking level control should be begun promptly to avoid loss of growth.

Table 3--Proportion of shelterwood plots stocked at various levels with 3-year-old and older advance and subsequent regeneration in 2 plant communities in the Cascade Range of eastern Oregon[1]

Stocking percent			Number of trees per acre		
Stocking at least	Plots	Proportion of total	Stocking at least	Plots	Proportion of total
Percent	Number		Number per acre	Number	
MOUNTAIN HEMLOCK/GROUSE HUCKLEBERRY--30 PLOTS					
20	29	0.97	200	30	1.00
40	23	.77	400	25	.83
60	16	.53	700	24	.80
80	4	.13	1,000	22	.73
			2,000	18	.60
			3,000	14	.47
MIXED CONIFER/SNOWBRUSH-CHINKAPIN--45 PLOTS					
20	44	.98	200	45	1.00
40	38	.84	400	42	.93
60	18	.40	700	34	.76
80	9	.20	1,000	28	.62
			2,000	14	.31
			3,000	9	.20

[1] Based on 1-milacre subplots.

Species Composition of Regeneration

The regeneration in both plant communities was composed of a mixture of species. In the mountain hemlock type, Shasta red fir was found on more milacre subplots than any other species (table 4). Grand fir and western white pine were also major species in the reproduction. For all origins combined, average stocking of the four major species is ranked as follows: Shasta red fir 43.5 percent, grand fir 14.1 percent, western white pine 10.0 percent, mountain hemlock 8.9 percent.

In the mixed conifer community, grand fir and red fir were the two major species--both occurred on the average on about 38 percent of the milacre subplots (table 4). Stocking of Douglas-fir (32 percent) was almost equal to that of the true firs, and ponderosa pine was the fourth most common species in the reproduction.

Table 4--Average stocking of advance and subsequent regeneration on shelterwood plots in 2 plant communities in the Cascade Range of eastern Oregon, by species[1/]

Species	Mountain hemlock/grouse huckleberry				Mixed conifer/snowbrush-chinkapin			
	Advance seedlings	Subsequent seedlings[2/] 3-year-old and older	Subsequent seedlings[2/] 1- and 2-year-old	All classes	Advance seedlings	Subsequent seedlings[2/] 3-year-old and older	Subsequent seedlings[2/] 1- and 2-year-old	All classes
	Stocking percent ± S.E.[3/]				Stocking percent ± S.E.[3/]			
Grand fir	0.8 ± 0.3	13.7 ± 3.2	4.1 ± 1.2	14.1 ± 3.7	5.6 ± 1.0	29.2 ± 3.0	10.5 ± 1.6	38.0 ± 3.5
Shasta red fir	5.9 ± 1.2	35.9 ± 5.0	23.9 ± 3.7	43.5 ± 5.9	1.1 ± .4	27.5 ± 9.1	10.8 ± 4.6	38.5 ± 17.6
Pacific silver fir	.1 ± .1	.2 ± .2	.2 ± .2	.3 ± .3	0 ± --	0 ± --	0 ± --	0 ± --
Douglas-fir	0 ± --	0 ± --	0 ± --	0 ± --	.6 ± .3	21.4 ± 6.2	9.7 ± 2.5	31.9 ± 13.3
Mountain hemlock	3.5 ± .9	4.4 ± 1.3	2.9 ± .8	8.9 ± 1.9	0 ± --	0 ± --	0 ± --	0 ± --
Engelmann spruce	0 ± --	1.5 ± 1.0	.8 ± .7	1.7 ± 1.2	0 ± --	.4 ± .4	.1 ± .1	.4 ± .4
Western white pine	.5 ± .3	6.9 ± 1.4	2.1 ± .7	10.0 ± 1.8	.5 ± .2	2.2 ± .6	1.9 ± .8	4.4 ± 1.3
Ponderosa pine	0 ± --	1.3 ± 1.3	0 ± --	1.3 ± 1.3	.2 ± .1	9.6 ± 1.8	2.6 ± 1.0	14.7 ± 4.6
Lodgepole pine	0 ± --	6.1 ± 1.7	1.5 ± .6	6.8 ± 1.8	.2 ± .1	3.7 ± 1.3	3.8 ± 1.8	6.7 ± 2.2

1/ Based on 1-milacre subplots.
2/ Includes natural and planted regeneration.
3/ S.E. = standard error.

Dominant Species

Although measurements of stocking and density give an indication of abundance and distribution of the regeneration, a classification that includes an estimate of vigor or size helps to give an insight into the species most likely to predominate in the immediate future. In mountain hemlock shelterwoods, the reproduction is composed of several dominant species; Shasta red fir, lodgepole pine, grand fir, and mountain hemlock occur most frequently (table 5). Regeneration of natural subsequent origin was dominant on about 56 percent of the stocked 4-milacre subplots; planted seedlings on 29 percent.

Although planted lodgepole pine was only a small component of the regeneration in number per acre, it was classified as dominant on 13.2 percent of the stocked 4-milacre subplots--the second largest species-origin combination. Planted red fir was dominant on about 10 percent of the stocked subplots, although it was planted only in minor amounts.

Reproduction of natural subsequent origin was also dominant on the largest number of stocked subplots (63 percent) in the mixed conifer shelterwoods (table 5), and again planted trees dominated on 29 percent of the subplots. Grand fir seedlings of subsequent

Table 5--Percent of stocked subplots by species and origin of dominant seedlings in 2 plant communities in the Cascade Range of eastern Oregon[1/]

Origin of seedlings	Grand fir	Shasta red fir	Douglas-fir	Mt. hemlock	Western white pine	Engelmann spruce	Ponderosa pine	Lodgepole pine	Total
				MOUNTAIN HEMLOCK/GROUSE HUCKLEBERRY					
Advance	0.9	5.0	--	7.7	0.6	0.4	--	--	14.6
Natural									
Subsequent	6.6	40.2	0.1	2.3	4.5	.5	--	2.3	56.5
Planted	2.7	9.8	--	--	1.6	--	1.6	13.2	28.9
Total	10.2	55.0	.1	10.0	6.7	.9	1.6	15.5	100.0
				MIXED CONIFER/SNOWBRUSH-CHINKAPIN					
Advance	6.1	1.0	0.4	--	.9	--	--	--	8.4
Natural									
Subsequent	27.7	14.4	11.1	--	2.7	--	3.7	3.3	62.9
Planted	1.1	2.1	7.8	--	.2	--	17.5	--	28.7
Total	34.9	17.5	19.3	--	3.8	--	21.2	3.3	100.0

1/ Based on 4-milacre subplots; 1- and 2-year-old seedlings included.

origin were dominant on about 28 percent of the stocked subplots--the single largest species-origin combination; planted ponderosa pine was the second largest category. Because of their greater height, planted seedlings are dominant on more of the stocked subplots than their small numbers would suggest.

Height growth of the regeneration was not systematically measured in this study, but observations of annual height growth of 2 to 3 inches were common on the 3-year-old and older seedlings (fig. 4).

Relation of Present Stocking and Density to Environmental Factors

The influence of observed environmental factors on regeneration and their relative

Figure 4.--Vigorous 5-year-old grand fir natural reproduction.

importance in descriptions of present stocking and seedling density were determined by stepwise regression analyses. The results of these analyses are presented in tables 6 and 7--the positive or negative relationship to stocking and density and the order in which variables appear in the equations.

In mountain hemlock shelterwoods, there was no correlation between understory vegetation and stocking or abundance of regeneration. This was expected, since, on the average only about 7 percent of the forest floor was occupied by forbs, shrubs, and grasses (table 1). In mixed conifer shelterwoods, however, the amount of understory vegetation was greater and was negatively correlated with density of regeneration (table 7). Heavy amounts of grass were especially detrimental to establishment of seedlings, and grasses entered as the first variable for all natural regeneration and 1- and 2-year-old reproduction.

Aspect appeared as a negative term in hemlock shelterwoods, indicating that regeneration was generally less on more northerly aspects (table 7). This was contrary to the expectation that northerly aspects are more favorable for natural regeneration as Seidel (1979b) found in mountain hemlock clearcuts. The reason is not clear, but one might speculate that perhaps a residual overstory does not allow sufficient insolation for optimum germination of seed on the cool, high elevation, northerly aspects in the mountain hemlock type. These results suggest that, in terms of natural regeneration, clearcutting is most useful on north to east aspects, whereas the shelterwood system has the advantage on south to west slopes. In the mixed conifer type, a more northerly aspect was associated with more regeneration.

An increase in elevation resulted in less regeneration in the hemlock type, and this variable was one of the first factors to enter the equations describing stocking (table 6); in the mixed conifer plots, elevation was positively related to reproduction. These are logical results since the environment for establishment of seedlings improves as the hot and dry conditions found at the lower elevations of the mixed conifer type give way to more

Table 6--Positive and negative correlations of variables and the order in which they appeared in regression equations describing stocking of regeneration in 2 plant communities in shelterwood units in the Cascade Range of eastern Oregon[1/]

Species or origin	Variable[2/]																
	Elevation	Aspect	Slope	Mineral soil	Litter	Slash	Litter and slash	Burn (pile and burn)	Forbs	Shrubs	Grasses	Basal area	Crown density	Residual trees per acre	Quadratic average diameter	R^2	Standard error of stocking percent
MOUNTAIN HEMLOCK/GROUSE HUCKLEBERRY																	
All regeneration	-2		-3	+5			+1				+4				+6	0.67	13.6
All natural regeneration	-2		-5	+6		+4	+1								+3	.73	14.8
3-year-old and older seedlings	-2					+5	+1				+3				+4	.68	15.2
1- and 2-year-old seedlings	-4		-2	+5			+3			-7	+6	+1				.60	12.8
Subsequent red fir			-3				+1								+2	.80	13.0
All red fir			-2	+4			+1					+3				.85	13.7
Subsequent white pine	-1	-3			-4		-7			-5			-2	-6		.76	4.4
All white pine	-2							+1					-3			.69	5.8
All mountain hemlock	-1			-4			-2	+5							-3	.77	5.4
MIXED CONIFER/SNOWBRUSH-CHINKAPIN																	
All regeneration		+5	+3					-4	-1			+2				.38	17.6
All natural regeneration		+5	+3	+4				-6	-1				+2			.38	21.8
3-year-old and older seedlings									-3		-2		+1			.26	20.8
1- and 2-year-old seedlings				+3							-2	+1				.34	18.4
Subsequent red fir	+1	+3				+5						+4			+2	.42	18.1
Subsequent grand fir	+3			+2				-4					+1			.46	15.5
Subsequent Douglas-fir	-1		+2				-4						+3			.34	13.3
All grand fir	+1			+3									+2			.40	18.8
All Douglas-fir	-1		+3									+2				.42	17.7
All red fir	+1	+5		+6		+7				-4				+3	+2	.50	19.5

[1/] Numbers indicate the order in which variables entered the regression equation.

[2/] Only the variables that accounted for the major portion of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

mesic conditions at the upper limits of the community. Conversely, seedling establishment decreases at higher elevations in the mountain hemlock type because of more severe microclimates (primarily low temperatures).

Basal area had a consistent positive relationship to density of regeneration and entered as the first variable for nearly all equations in the mountain hemlock type (table 7), but crown density did not appear as one of the first factors. Crown density was related to the dependent variables about as strongly as was basal area. Because of the high degree of correlation between basal area and crown density (fig. 5), however, when one of these variables entered an equation, the other variable no longer contributed greatly to the explained variation. In the mixed conifer shelterwoods, both basal area and crown density were positively related to regeneration, but again not in the same equation.

It is apparent that the effect of these variables on stocking and density of regeneration depends on both the species and origin of reproduction and the plant community. In general, the effect of these variables on stocking and

Table 7--Positive and negative correlations of variables and the order in which they appeared in regression equations describing density of regeneration in 2 plant communities in shelterwood units in the Cascade Range of eastern Oregon[1/]

Species or origin	Variable[2/]																
	Elevation	Aspect	Slope	Mineral soil	Litter	Slash	Litter and slash	Burn (pile and burn)	Forbs	Shrubs	Grasses	Basal area	Crown density	Residual trees per acre	Quadratic average diameter	R^2	Standard error of seedling density
MOUNTAIN HEMLOCK/GROUSE HUCKLEBERRY																	
All regeneration	-5	-4			-2							+1			+3	0.65	2,607
All natural regeneration	-4		-5	+6	-2							+1			+3	.70	2,528
3-year-old and older seedlings	-3	-5			-4							+1		-2		.68	1,975
1- and 2-year-old seedlings	-6		-3	+4	-2							+1			+5	.63	678
Subsequent red fir					-3							+1		-2		.66	2,547
All red fir					-3							+1		-2		.68	2,507
Subsequent white pine	-2	-5						+1			-4	-3				.76	74
All white pine		-3					+4	+1			-2					.73	112
Subsequent mountain hemlock	-7	-6			-5		-3	+1		+4				+2		.81	72
All mountain hemlock	-1						-2		+3						-4	.77	85
MIXED CONIFER/SNOWBRUSH-CHINKAPIN																	
All regeneration					-5				-1	-4	-2		+3			.33	3,098
All natural regeneration					-5				-4	-3	-1		+2			.33	3,140
3-year-old and older seedlings	+4	+3		+2									+1		+5	.38	1,639
1- and 2-year-old seedlings					-4				-5	-2	-1	+3					
Subsequent grand fir	+3			+2						-5	-4		+1			.34	1,435
All grand fir	+3			+2						-5	-4		+1			.33	1,477
Subsequent Douglas-fir	-2		+4	+5							-3	+1				.46	562
All Douglas-fir	-2		+4	+3								+1				.42	572
Subsequent red fir	+3	+5		+2		+6							+1	+7	+4	.48	1,029
All red fir	+2	+5		+4		+6							+1	+7	+3	.47	1,049

1/ Numbers indicate the order in which variables entered the regression equation.

2/ Only the variables that accounted for the major portion of the variation in density of seedlings are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

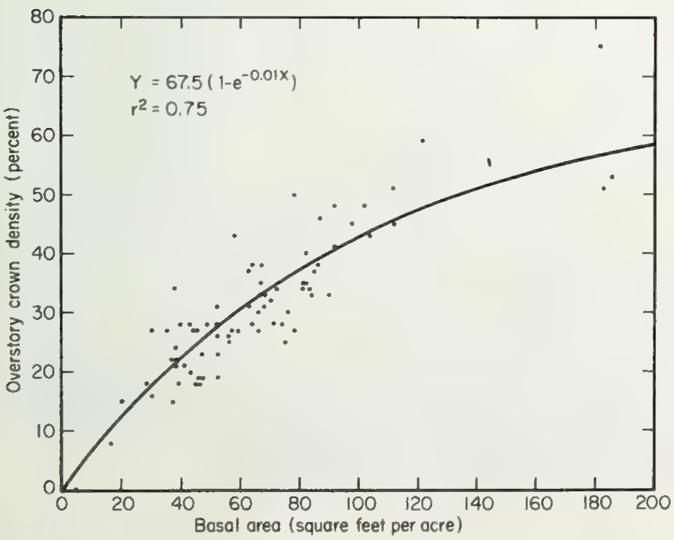

Figure 5.--Relationship between basal area and crown density of residual overstory for all shelterwood plots in both mountain hemlock and mixed conifer plant communities in the eastern Cascade Range.

abundance of regeneration in the mountain hemlock and mixed conifer communities can be summarized by listing the variables associated with increased stocking, decreased stocking, or having no strong relationship to stocking as follows:

MOUNTAIN HEMLOCK COMMUNITY

Increased stocking	Decreased stocking	Little relationship
More mineral soil	Higher elevation	Slash
More litter and slash	Greater slope	Burn
More basal area	More litter	Forbs
Greater average diameter of the overstory	More northerly aspect	Shrubs
		Grasses
		Crown density
		Overstory trees per acre

MIXED CONIFER COMMUNITY

Increased stocking	Decreased stocking	Little relationship
Higher elevation	More litter	Slash
More northerly aspect	Greater severity of burn	Litter and slash
Greater slope	More forbs	Overstory trees per acre
More mineral soil	More shrubs	Average diameter of overstory
More basal area	More grasses	
Greater crown density		

The indication that more litter and slash lead to increased stocking in the mountain hemlock community, whereas more litter decreases stocking appears to be a contradiction. The increased stocking associated with litter and slash probably is due to the effect of slash more than litter and may reflect some difficulty in classification of seed beds into the litter, slash, and litter and slash categories. In any case, the relationships between condition of the seed bed and establishment of natural regeneration are evident from the data and observations in this study and other studies. Mineral soil is clearly the most favorable seed bed for establishment of seedlings in both plant communities, but I observed many seedlings growing in light to medium litter layers (1/4 to 1/2-inch-deep). Heavy, continuous litter mats (more than 1/2-inch- thick) severely reduce the number of seedlings. Similarly, many seedlings were found growing in the shade of light amounts of slash throughout the shelterwood plots, but very few in deep concentrations of slash (fig. 6). Similar

Figure 6.--Seedlings growing in shade of slash.

conditions were observed in another shelterwood study in a mixed conifer plant community in central Oregon (Seidel 1979a). Therefore, it is not necessary or desirable to completely remove all litter and slash from the seed bed. Enough disturbance is caused by logging and slash disposal to provide a receptive seed bed.

Some light damage to the regeneration by animals was observed on these shelterwood plots. In the mountain hemlock type, damage caused by gophers was found on about 1 percent of the subplots compared with 7 percent in the mixed conifer community. Damage by other animals (primarily deer) was observed on 4 percent of the subplots in the hemlock plots and 7 percent in the mixed conifer.

Prediction Equations

Reliable equations to predict stocking or density of regeneration after shelterwood cutting would be useful. The regression equations summarized in the preceding section include variables--such as grasses, forbs, and shrubs--that change with time--similar to the change in stocking--and therefore cannot be used for predicting stocking. To derive prediction equations, I used only the variables that remain independent and can be measured before or directly after harvest.[3] Variables used were elevation, aspect, slope, slash, degree of burn, basal area, crown density, number of overstory trees per acre, and average diameter. Strictly speaking, amount of slash and degree of burn do not remain completely unchanged over time; but within the timespan this study covers, they changed little. Basal area, trees per acre, and average diameter were adjusted to values immediately after the seed cut by adding data from dead and down trees.

Because of the large amount of unexplained variation present, it is not possible to accurately predict regeneration stocking after shelterwood cutting in either the mountain hemlock or mixed conifer communities (tables 8 and 9). In

[3] Variables that remain independent are those that are unchanged or nearly so over time or can be adjusted to preharvest values. For example, understory vegetation was not used because it can vary during the time after the seed cut, similar to tree regeneration.

Table 8--Prediction equations for milacre stocking of regeneration on shelterwood units in a mountain hemlock/grouse huckleberry community in the Cascade Range of eastern Oregon, by species and class of reproduction

Dependent variable	Equation[1]	Variation explained R^2	Standard error of estimate Sy·x
		- - - Percent - - -	
1- and 2-year-old seedlings	=15.91+0.28(basal area)-11.48(slope)	0.37	14.5
3-year-old and older seedlings	=231.22+0.02(crown density)-0.04(elev.) +2.36(average diameter)+16.17(slash)-1.68(aspect) -22.44(burn)	.50	19.6
All natural regeneration	=258.12-0.05(elev.)+2.28(average diameter) +9.66(slash)-21.42(burn)	.45	20.2
All regeneration	=182.29+0.08(basal area)-0.02(elev.) -1.46(aspect)+0.98(average diameter)	.29	19.1
Subsequent red fir	=-16.25+2.33(average diameter)-31.87(burn)	.47	21.0
All red fir	=-4.81+0.29(basal area)-34.08(burn)	.49	24.6
Subsequent white pine	=103.83-0.01(elev.)-0.37(crown density) -0.66(aspect)	.57	5.5
All white pine	=108.39+9.29(burn)-0.02(elev.) -0.39(crown density)	.69	5.8
All hemlock	=85.71-0.01(elev.)-0.58(average diameter) +12.09(burn)	.66	6.3

[1] Variables are arranged in the order in which they entered the regressions. Only the variables that accounted for major portions of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

the mountain hemlock plots, the equation predicting milacre stocking of all white pine accounted for the most variation (69 percent); the equation for all regeneration accounted for the least (29 percent). The equations showed that the establishment of

Table 9--Prediction equations for milacre stocking of regeneration on shelterwood units in a mixed conifer/snowbrush-chinkapin community in the Cascade Range of eastern Oregon, by species and class of reproduction

Dependent variable	Equation[1/]	Variation explained R^2	Standard error of estimate $S_{y \cdot x}$
		- - - Percent - - -	
Subsequent red fir	=-214.96+0.03(elev.)+1.40(average diameter) +0.84(aspect)+0.15(basal area)+7.00(slash)	0.42	18.1
Subsequent grand fir	=-57.36+0.51(crown density)+0.01(elev.)	.26	17.5
Subsequent Douglas-fir	=99.29-0.02(elev)+8.12(slope) +0.26(crown density)	.31	13.4
All grand fir	=-48.28+0.02(elev.)+0.55(crown density) -6.68(slash)	.32	20.0
All Douglas-fir	=134.98-0.03(elev.)+0.20(basal area) +13.06(slope)	.42	17.7
All red fir	=-231.71+0.04(elev.)+2.00(average diameter) +0.61(trees/acre)+7.50(slash)	.39	20.7
1- and 2-year-old seedlings	=-3.44+0.30(basal area)+0.77(aspect) +7.86(slope)	.25	19.7
3-year-old and older seedlings	=19.17+0.68(crown density)+9.32(slope)	.17	21.8
All natural	=17.26+0.74(crown closure)+15.53(slope) +0.98(aspect)	.23	23.5
All regeneration	=-33.06+0.27(basal area)+0.01(elev.) +10.33(slope)+0.79(aspect)	.32	18.1

[1/] Variables are arranged in the order in which they entered the regressions. Only the variables that accounted for major portions of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

white pine (a shade-intolerant species) was reduced by heavier residual overstories compared with the more shade-tolerant species which were favored by increasing stand densities. The amount of

variation explained by the equations was similar for mixed conifers and mountain hemlock and ranged from 17 percent for 3-year and older regeneration to 42 percent for all Douglas-fir (table 9).

Although these equations are not accurate enough for predictions, they are probably as good as can be expected when the variables involved and complex distribution pattern of natural regeneration are considered. Unexplained variation exists for several reasons. In a survey study, no estimate of the amount of seed fall on the shelterwood units is obtainable. In addition, factors measured (aspect, slope, etc.) are secondary variables. These variables influence the five primary variables (light, temperature, moisture, and chemical and physical factors) in which seedlings respond directly. Finally, it should be mentioned that, ideally, equations such as these should be verified on an independent set of data not used in their derivation. Therefore, I want to emphasize that these equations should not be considered precise predictors of expected regeneration after shelterwood cutting but only crude estimates of possible stocking.

Residual Stand Density and Regeneration

The question of the appropriate stand density to leave after the seed cut is important to land managers. Although the equations in this study do not permit an accurate estimate of expected regeneration, some idea of the general trend of reproduction as stand density varies and the range of stand densities most suitable for regeneration can be obtained from these data and similar studies.

In both plant communities, there is a general trend of increasing stocking as stand density (basal area) increases and a large amount of unexplained variation in stocking (fig. 7). It appears that there is no problem in obtaining an abundance of natural regeneration at relatively high

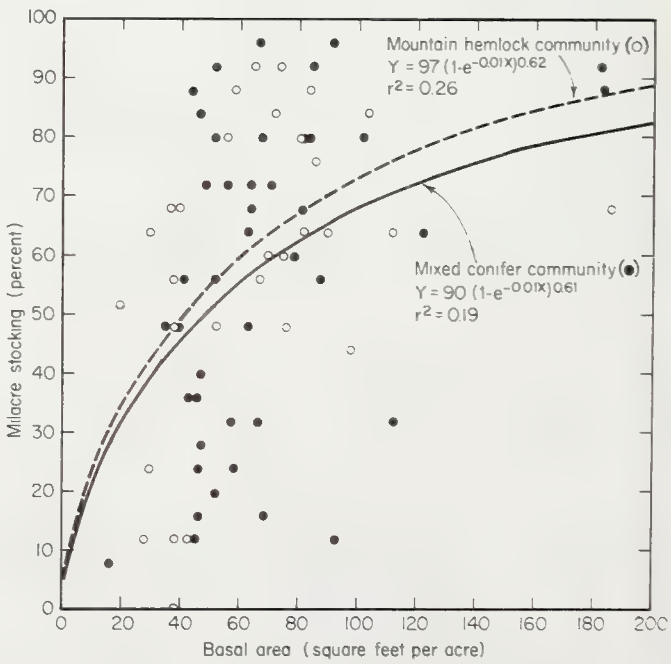

Figure 7.--Relationship between basal area and milacre stocking of natural regeneration in the mountain hemlcok and mixed conifer plant communities in the Cascade Range of eastern Oregon.

stand densities of over 100 square feet per acre. When the shelterwood system is used in the general forest zone, however, residual stand density should be reduced to the minimum level at which an acceptable amount of regeneration will be obtained. Also, the established reproduction must not be excessively damaged or destroyed during removal of the overstory and disposal of slash. My observations suggest that if at least 40-percent stocking of milacre plots is desired, then a basal area of about 60 square feet per acre should result in adequate stocking on most units. A few shelterwood plots were 50 to 70 percent stocked with residual basal areas as low as 30 to 40 square feet per acre, but the probability of failure of regeneration increases at this low density.

Basal area and elevation were two variables that appeared in many of the prediction equations. Their relationship to milacre stocking is illustrated in figure 8.[4] Although not accurate enough for predictions, these curves show the wide range of basal area where stocking occurs, the increase in stocking with

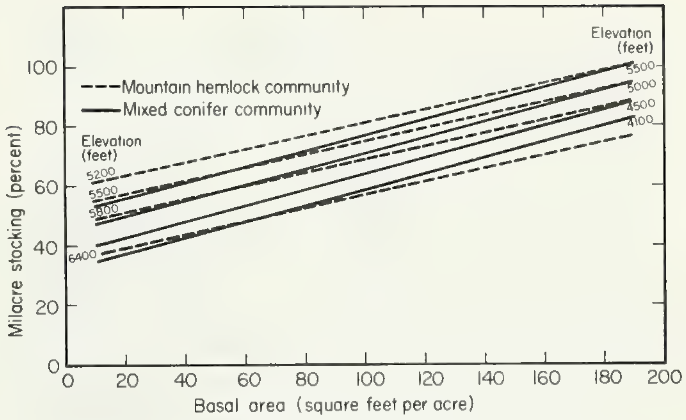

Figure 8.--Relationship between basal area, elevation, and milacre stocking of all regeneration in the mountain hemlock and mixed conifer plant communities in the Cascade Range of eastern Oregon.

elevation in the mixed conifer type, and the decrease in stocking at higher elevations in the mountain hemlock type. Even though milacre stocking of 40 to 60 percent is indicated by these curves at basal areas of 20 to 30 square feet per acre, the wide scatter of these data suggests that a residual stand density that low will probably result in some understocked units.

The range of stand densities where adequate natural regeneration occurred in this study was similar to that found in several other shelterwood studies in central Oregon. In a single mountain hemlock stand, Seidel and Cooley (1974) estimated that about 80 square feet of basal area per acre was needed in the residual overstory for adequate reproduction of grand fir. And Seidel (1979a) found in a mixed conifer community that good regeneration

[4] Mountain hemlock equation is $Y = 163.38 + 0.22$ (basal area) -0.02 (elevation) $R^2 = 0.23^*$, standard error of estimate = 19.2 percent. Mixed conifer equation is $Y = -20.62 + 0.26$ (basal area) $+ 0.013$ (elevation) $R^2 = 0.25^{**}$, standard error of estimate = 18.6 percent.

of true fir was established under a residual overstory of 50 square feet per acre. It is apparent from these studies that natural regeneration in the mixed conifer and mountain hemlock plant communities is established under a wide range of residual stand densities and that, because of the many variables affecting reproduction, no single level is suitable in all areas. A range of 60 to 80 square feet of basal area per acre is suggested as the minimum level for natural regeneration to occur on nearly all shelterwood units.

Natural Regeneration Versus Planting

Because of the good to excellent natural regeneration that occurred on most of the shelterwoods plots, planting does not seem necessary when considered only in terms of the contribution of the planted seedlings to total numbers of seedlings. Only 5 to 10 percent of the total number of seedlings in planted plots was planted stock. As discussed previously, however, the advantages of planting lie not with seedling numbers but with the good distribution and greater height of the planted seedlings.

In the mixed conifer community, planting increased stocking on 29 of the 43 planted plots; on 9 of these plots, stocking was raised by more than 12 percent. Obviously, the effect of planting is greatest on units where natural regeneration is light; planting can then be the difference between an understocked and an adequately stocked stand. For example, using a 40-percent stocking of milacre quadrats as representing adequate regeneration, planting increased stocking on 10 mixed conifer plots from less than 40 percent to above the 40-percent level. The only apparent common factor related to lack of natural regeneration on these plots was a light residual overstory. After the seed cut, 7 of the 10 plots had less than 60 square feet of basal area.

On the 15 shelterwood units planted in the mountain hemlock community, on only 1 was stocking increased above 40 percent by the planted seedlings. Although planting was generally not needed to insure an adequately stocked stand in this plant community, there appears to be a relationship between species composition of the overstory and a need for planting. On the plots where the overstory consisted of a mixture of species, natural regeneration was good to excellent, even at residual densities of less than 60 square feet per acre, and planting was not needed. On the other hand, natural regeneration was poor on plots where the overstory was 100 percent mountain hemlock and planted seedlings made up 70 percent of the reproduction.

The amounts of understory vegetation that became established on these shelterwood plots after the

seed cut were small, especially in the mountain hemlock community where only about 7 percent, on the average, of the seed bed was occupied (table 1). The absence of heavily competing vegetation for a number of years, together with the high probability of a heavy seed crop every 3 to 4 years as reported by Franklin et al. (1974) in mixed conifer stands and the good distribution of seed trees over the area, results in a high probability of success of natural regeneration.

Because of the abundant natural regeneration that can be expected within a few years after the seed cut, planting appears better suited as a supplemental means of reforestation to raise stocking above minimum standards. The most efficient use of planting in the shelterwood system is probably to increase stocking where removal of the residual overstory has reduced stocking below minimum standards. Planted seedlings are then not subject to loss or damage by logging operations as they are when planted before the overstory is removed.

In summary, results of this study suggest that planting shelterwood units immediately after the seed cut is necessary only in the following cases: (1) in mixed conifer communities if residual basal area is reduced below 60 square feet per acre and (2) in pure mountain hemlock communities containing no other species in the overstory.

Overstory Mortality

Mortality of the residual overstory after the seed cut was greater in the mountain hemlock plots than in the mixed conifer community. An average of 2.4 trees per acre were blown down and 1.7 trees per acre were standing dead in the mountain hemlock type. This amounted to about 16 percent of the total number of trees left after logging. In the mixed conifer community, about 6 percent of the overstory was lost--an average of 0.5 tree per acre blown down and 0.6 tree per acre standing dead.

Blowdown can be a problem when the shelterwood system is used in unmanaged old-growth stands because trees growing at high densities have not developed the windfirmness needed to resist greater stresses from wind after heavy partial cuts. Mountain hemlock is especially susceptible because of its relatively shallow root system (fig. 9). The risk of blowdown can be reduced by leaving dominant or codominant, full-crowned trees which are the most windfirm and also the best seed producers (Gordon 1973). Mountain hemlock should be discriminated against in favor of the other species in the overstory when the seed cut is marked. This not only reduces the chance of blowdown but also increases the chance of regeneration success by providing more seed of species, such as the true firs, that apparently regenerate better than mountain hemlock

at stand densities from 60 to 80 square feet per acre.

Figure 9.--Blowdown of mountain hemlock.

CONCLUSIONS AND RECOMMENDATIONS

The results of this survey indicate that use of the shelterwood system can provide satisfactory natural regeneration of a number of species in terms of stocking and seedling density in both mixed conifer/snowbrush-chinkapin and mountain hemlock/grouse huckleberry plant communities. Obtaining adequate natural regeneration depends on many factors. Two of the most important are a sufficient and uniform overstory density and a seed bed receptive to establishment of seedlings. A uniform residual overstory in the range of 60 to 80 square feet of basal area per acre is recommended for natural regeneration in both plant communities. Adjustments in the basal area level can be made for various aspects, slopes, or elevations by use of the prediction equations; that they provide only very rough estimates of expected stocking because of the considerable amount of unexplained variation must be considered. A suitable seed bed is provided by logging and slash disposal operations, which serve to break up heavy litter layers and expose mineral soil. A heavy seed year soon after the seed cut provides the best chance of securing regeneration immediately; but, because competing understory vegetation is not a serious problem, seed beds remain receptive and adequate stocking can be obtained over a period of years from a number of light seed crops.

Planting on these shelterwood units served mainly as a supplemental rather than a primary means of reforestation. Seedlings should be planted in mixed conifer shelterwood units immediately after the seed cut if overstory density is less than 60 square feet per acre and in mountain hemlock shelterwoods where the overstory consists only of mountain hemlock. Otherwise, natural regeneration should be relied on. If natural regeneration has not resulted in adequate stocking after 3 or 4 years in unplanted units, the land manager can then (1) underplant to raise stocking to satisfactory levels or (2) remove the residual overstory and then plant. Alternative 2 is recommended because planted seedlings are then not subject to loss or damage from logging and slash disposal operations. Ponderosa pine and Douglas-fir are the preferred species to plant in mixed conifer communities; lodgepole pine and the true firs survive and grow well in the mountain hemlock type. Planting stock grown from seed collected in the same geographical and elevational zone as the shelterwood unit should be used.

The residual overstory in shelterwood units should consist of only the most vigorous dominant or codominant trees. This objective is accomplished better if the leave trees rather than cut trees are marked. This focuses the marker's attention on the most desirable trees to leave and also reduces the tendency to leave too heavy an overstory, which sometimes occurs when the cut trees are marked.

It is clear from the results of this and other studies that adequate natural regeneration is obtained when the shelterwood system is used in mixed conifer and mountain hemlock plant communities in the Cascade Range of eastern Oregon. Establishment of a satisfactory stand of reproduction after the seed cut, however, is only part of the reforestation job when the shelterwood system is used. Unless the residual overstory can be removed without causing unacceptable loss and damage to the regeneration, all the time and effort involved in securing regeneration have been wasted. Although there are many mixed conifer shelterwood units in the Cascades where the seed cut has been made, the residual overstory has been removed on very few; so experience is lacking regarding the best procedures. Limited experience, however, has shown that it is possible to remove an overstory of 24,000 board feet per acre and still preserve ponderosa pine saplings (Barrett et al. 1976). And McDonald (1976) reported that up to 10 overstory trees per acre were removed from shelterwood units in California without excessive loss of reproduction.

The key to saving the regeneration is good coordination

between timber and fuels management staffs and the skillful application of logging techniques designed to preserve the established reproduction. After studying logging methods in mixed conifer stands in Arizona, Gottfried and Jones (1975) suggested several changes to reduce loss and damage to regeneration. They include:

1. Marking and clearing skid trails.--Skid trails should be marked on the ground and the same trails used for all cuts. Windfalls are commonly found lying across skid trails when the overstory is removed. Pushing these tree length windfalls out of trails does considerable damage to the reproduction. Damage can be avoided by having a swamper preclear skid trails by sawing out sections of the blowndown trees and then pushing them into areas where damage would be least.

2. Directional falling and variable log lengths.--Trees should be felled in a herringbone pattern so that logs can be pulled onto skid trails with the least disturbance. Trees should be felled into openings in preference to maintaining a strict herringbone pattern. Trees lying at a poor angle for winching to skid trails should be bucked into 16-foot logs rather than 32-foot logs. Tractors should stay on trails and back toward direction of fall.

3. Careful winching.--Restricting tractors to marked and precleared skid trails would require more winching. Logs being winched to a tractor sometimes catch on down material and drag it sideways, destroying and damaging regeneration. A swamper or the choker setter could saw out sections that lay in the way, making winching easier and reducing damage to the reproduction.

4. Yarding unmerchantable material.--Moving unmerchantable logs to landings will reduce the amount of material that must be handled in the slash disposal operations.

5. Season of logging.--Logging on snow offers possibilities for reducing root damage and destruction of fewer trees. Logging operations should be avoided, if possible, during the spring when terminal shoots are tender and easily broken and at times when freezing conditions make stems brittle.

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APPENDIX

Independent (X) variables used in regression analyses.

1. Elevation. The average elevation of the plot to the nearest 10 feet as measured with an altimeter.

2. Aspect. One of eight compass points measured on each subplot. The method proposed by Day and Monk (1974) was used to code the aspect, and the following values were assigned to compass directions: N - 14; NE - 15; E - 11; SE - 7; S - 3; SW - 2; W - 6; NW - 10. Average coded value of the 25 subplots was used in analyses.

3. Slope. Percentage slope of each subplot was measured with a clinometer and coded as follows: 0-9 percent, 0; 10-19 percent, 1; 20-29 percent, 2; 30-39 percent, 3; etc. Average coded value of subplots was used.

4. Mineral soil. The percentage of each subplot containing mineral soil was estimated, coded in the same way as slope values, and averaged.

5. Litter. The percentage of each subplot covered with litter was estimated, coded in the same way as slope values, and averaged.

6. Slash. The percentage of each subplot covered with slash was estimated, coded in the same way as slope values, and averaged.

7. Litter and slash. The percentage of each subplot covered with litter and slash was estimated, coded in the same way as slope values, and averaged.

8. Degree of burn. Estimated on each subplot and coded as: None, 0; light, 1; medium, 2; heavy, 3. Averaged coded value was used in analyses. Degree of burn is defined as: None--no visible effect of fire; light--fire charred the surface of the forest floor but did not remove all the litter layer; medium--fire removed all the litter layer and some of the duff; heavy--fire removed all the litter and duff and imparted a color to the mineral soil.

9. Forbs. The percentage of each subplot covered with forbs was estimated, coded in the same way as slope values, and averaged.

10. Shrubs. The percentage of each subplot covered with shrubs was estimated, coded in the same way as slope values, and averaged.

11. Grasses and sedges. The percentage of each subplot covered with grasses and sedges was estimated, coded in the same way as slope values, and averaged.

12. Basal area. The overstory basal area at each subplot was measured with a 10-factor angle gage and averaged for use in analyses.

13. Crown density. The overstory crown density or closure was measured with a spherical densiometer at each subplot by Strickler's (1959) method. Average value of the 25 subplots was used in analyses.

14. Overstory trees per acre. The numbers of standing overstory trees (living and dead) and blown down trees were recorded on 0.0785-acre subplots at each of the 25 sample points, averaged, and converted to a per-acre basis.

15. Overstory average diameter. The diameters at breast height of living and dead standing trees and blown down trees on each 0.0785-acre subplot were measured to the nearest inch and averaged.

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A survey of shelterwood cuttings in mixed conifer forests in the eastern Oregon Cascade Range showed that, on the average, shelterwood units were well stocked with a mixture of advance, natural subsequent, and planted reproduction of a number of species. Because of slow invasion by understory vegetation, frequent heavy seed crops, and adequate density of the overstory, natural regeneration was prolific on most units. Planting is recommended only as a supplemental reforestation method. Greater stocking was associated with increasing overstory density and more exposed mineral soil; such factors as aspect, slope, and elevation had a positive or negative relationship to stocking depending on the species and plant community.

KEYWORDS: Regeneration (stand), regeneration (natural), regeneration (artificial), mixed stands, Oregon (Cascade Range), shelterwood cutting method.

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